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APPLICANT : Nicholas R. White
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FILED : March 24, 2004
FOR : "ELECTROMAGNETIC REGULATOR ASSEMBLY FOR ADJUSTING AND CONTROLLING THE CURRENT UNIFORMITY OF CONTINUOUS ION BEAMS"
EXAMINER : Nikita Wells
GROUP ART UNIT : 2881
ATTORNEY'S DOCKET NO. : NWHT-001

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Attorney for applicant: David Prashker

Signature: [signature]

Date: June 2, 2005

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MARKED UP VERSION OF AMENDED SPECIFICATION SUBMITTED
PURSUANT TO 37 C.F.R.1.121(b)(1)(ii)

Commissioner for Patents
P.O. Box 1450
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Alexandria, Virginia 22313-1450

Sir:

Applicant, in fulfillment of and in accordance with the requirements of 37 CRF 1.121(b)(1)(ii), hereby submits a marked-up version of the present amendments to the Specification which appear at the following locations:

Page 4, lines 11 and 18.

Page 5, lines 5, 6 and 12.

Page 9, lines 17, 18, 19, 21 and 22.

Page 10, lines 1, 2, 3, 5, 6, 7, 8, 9, 11, 13, 15, 17, 18, 20 and 22.

Page 11, lines 1 and 2.

Page 15, line 10.

Page 16, line 18.

Page 17, lines 8, 11, 15, 17 and 20.

Page 19, line 10.

Page 20, lines 5 and 12.

Page 21, lines 3, 5, 9, 10 and 13.

Page 22, line 4.

Page 24, line 3.

Page 26, line 1.

Page 27, line 3.

Page 28, line 20.

Page 30, lines 9 and 12.

Page 34, line 2.

REMARKS

Via the Notice Of Allowance And Fee(s) Due mailed March 17, 2005 for the above-identified application, the Examiner of record has made a requirement for a new corrected formal Drawing because the originally submitted figures were not numbered consecutively.

This Examiner-imposed requirement has thus indirectly and concomitantly demanded that applicant now also amend and renumber each specific reference to any of the individual original figures within the Specification such that the figure numbers recited in the written text will correspond to the enclosed consecutively numbered Replacement Sheets constituting new substitute Figs. 1-17 respectively. It is for this reason, and solely for this reason alone, that the present amendments to the Specification text are made.

Respectfully submitted,

NICHOLAS R. WHITE

Date: June 2, 2005

By: [signature]

David Prashker
Registration No. 29,693
Attorney for applicant
P.O. Box 5387
Magnolia, Massachusetts
Tel.: (978) 525-3794

deflections produce a characteristic variation in the current density for the ion beam, in which one region typically exhibits a decrease in ion density while a neighboring region exhibits an increase in ion density. See for example, U.S. Patent Nos. 5,834,786 and 5,350,926 for additional details of this arrangement.

(iv) Algorithms for adjusting multipole devices to achieve a greater degree of current density uniformity have been developed by Diamond Semiconductor Group Inc. and are typically used in the manufacture of their commercial products. However, such algorithms are very complicated in their specifics; and are quite difficult to implement in practice as a functional part of an ion implantation system.

(v) One conventionally known format of a multipole lens [*e.g.,* Banford, in *The Transport of Charged Particle Beams*, Spon, 1960] is shown by Prior Art Fig. ~~A~~ 1. As seen therein, the multipole lens is conceived with rotational symmetry. The magnetic field generated therein can be expressed in terms of cylindrical harmonics, and is best described using a polar coordinate system. Such lenses are used in various applications of generally cylindrical ion beams, such as electron microscopes and accelerators, where they can control aberrations of the system optics.

(vi) Attention should also be given to the "Panofsky" quadrupole lens design described by Banford [in *The Transport of Charged Particle Beams*, Spon, 1960] and illustrated by Prior Art Fig. ~~B~~ 2. This multipole format uses a closed rectangular yoke of iron to make a quadrupole lens for a beam of high aspect ratio. The windings on the two long member pieces of the yoke, which extend in one direction, must carry the same ampere turns (but in the opposite sense) to the two windings on the short member pieces that close the yoke and are oriented in the other direction. Both pairs of windings must be uniform in cross section in order to generate a uniform field gradient within the central region. The windings on oppositely positioned sides of the yoke

are electrically excited to yield a zone of linearly varying magnetic field, *i.e.* $dB_y/dx = - dB_x/dy$, which is approximately constant within the space bounded by the coils.

(vii) Another previously known format is the "Cartesian" multipole lens of White *et al.* [disclosed in the IIT '98 conference published by IEEE] which conforms to the shape of a ribbon beam, and is illustrated by Prior Art Figs. ~~C~~ 3 and ~~D~~ 4 respectively. The device (shown in cross-sectional view by Fig. ~~C~~ 3 and in a detailed sectional view by Fig. ~~D~~ 4) is a rectangular multipole lens which conforms to the shape of a ribbon beam in order to control its uniformity; and is often referred to as a Cartesian multipole - since it is best described in Cartesian coordinates, rather than by polar coordinates. Accordingly, this multipole lens produces a field component "B_y" whose variation along the x-axis can be controlled directly, by varying the current of the coils at different x-coordinates, with a resolution determined by the pitch of the coils and poles. Prior Art Fig. ~~E~~ 5 shows the effect of exciting a single pair of coils within this "Cartesian" multipole on an otherwise uniform ion beam.

In most types of systems using continuous ribbon beams, provision is made to move the workpiece to be implanted through the ion beam, in the direction of its short dimension, at a controlled velocity effective to achieve the correct dose of ions. In some systems a single passage is used, and in others each workpiece moves multiple times through the ion beams. The advantage offered by this technique is that minor beam size fluctuations in the y-axis direction have no net effect on the uniformity of the processing.

Overall therefore, many of these previously known structures and conventional ion implantation systems have been commercially utilized; have been technically successful in some meaningful degree; and have been reported within the technical literature with complete descriptions of their use and manner of operation. It is noteworthy, however, that the multipole

coil independently and concurrently generates an orthogonally extending and individually adjustable magnetic field of limited breadth between said first and second linear multipole arrays, and whereby said plurality of adjacently extending magnetic fields of limited breadth collectively form a contiguous magnetic field between said first and second linear multipole arrays, and whereby each magnetic field of limited breadth within said contiguous magnetic field can be individually and concurrently altered at will to yield an adjustable and controllable magnetic field gradient over said contiguous magnetic field; and

a circumscribed spatial passageway existing between said first and second linear multipole arrays for applying a contiguous magnetic field to and adjusting and controlling the magnetic field gradient of an applied contiguous magnetic field for a continuous ion beam traveling therethrough, wherein said spatial passageway is dimensionally circumscribed in a x-axis direction by said fixed length of said support rods of said first and second linear multipole arrays, and in a y-axis direction by said preset gap distance separating the coils of said first linear multipole array from the coils of said second linear multipole array, and wherein the degree of uniformity for the charged particles of a continuous ion beam becomes adjusted and controlled.

BRIEF DESCRIPTION OF THE FIGURES

Prior Art Fig. ~~A~~ 1 shows a conventional sextupole lens for an ion beam;

Prior Art Fig. ~~B~~ 2 shows a 'Panofsky' quadrupole;

Prior Art Fig. ~~C~~ 3 shows a cross-sectional view of a 'Cartesian' multipole of White et al. which is used for controlling beam uniformity;

Prior Art Fig. ~~D~~ 4 shows an overhead detailed sectional view of the 'Cartesian' multipole of Fig. ~~C~~ 3;

Prior Art Fig. ~~B~~ 5 shows the effect of exciting a single pair of coils in the 'Cartesian' multipole of Fig. ~~C~~ 4 on an otherwise uniform ion beam;

Fig. ~~1A~~ 6 shows a perspective view of the simplest construction for the regulator assembly of the present invention;

Fig. ~~1B~~ 7 shows a perspective view of a single multipole coil array in the regulator assembly of Fig. ~~1A~~ 6;

Fig. ~~2~~ 8 shows the effect of exciting an individual coiled winding in the regulator assembly of ~~fig. 1~~ Fig. 6 upon an ion beam that was otherwise uniform and parallel;

Fig. ~~3~~ 9 shows the effect of the regulator assembly of Figs. 6 and 7 where a parallel, but non-uniform, beam is rendered uniform at the expense of its parallelism;

Fig. ~~4~~ 10 is an illustration of the separation between the individual magnetic fields generated by two energized wire coils of the linear multipole array of the present invention;

Fig. ~~5~~ 11 is a graph showing the relationship between coil current, the field, and field gradient;

Fig. ~~6~~ 12 is a graph showing the relationship between field gradient and beam uniformity;

Fig. ~~7~~ 13 shows a perspective view of a preferred construction of the present invention;

Fig. ~~8~~ 14 shows another view of the preferred construction of Fig. ~~7~~ 13 as seen from the direction of the ion beam;

Fig. ~~9~~ 15 illustrates the arrangement where a ferromagnetic spacer is used to separate each of the adjacently positioned wire coils of the linear multipole array;

Fig. ~~10~~ 16 shows the incorporation of the present invention into a conventionally known ion implanter device; and

Fig. ~~11~~ 17 shows the structural differences between the orthogonally wound and positioned wire coils of the present invention and the coils of the prior art structure of Figs. ~~C~~ 3 and ~~D~~ 4.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is an electromagnetic regulator assembly which can adjust and control the degree of uniformity for charged particles traveling within a continuous ion beam. The invention comprises an article of manufacture and a method for adjusting the concentration of charged particles carried in such continuous ion beams. The instant invention thus provides an effective arrangement and means for controlling the uniformity of the ion current along the transverse direction of ribbon-shaped, continuous beams which are targeted at a plane of implantation or a work surface for the placement of charged ions into a prepared workpiece (such as a silicon wafer), which is passed through the beam orthogonal to its long direction in order to implant the whole of one face of the workpiece.

I. Definitions:

In order to avoid inconsistencies in terminology, eliminate ambiguities in denotative and connotative meanings, and to increase the clarity and completeness of comprehension and understanding, a set of carefully recited definitions are presented below. These terms and jargon will be employed consistently and repeatedly herein to describe and claim the present invention in a manner that not only sets forth what the present invention is and how it is to be made and used, but also separates and distinguishes the inventive subject matter from what it is not.

varies smoothly between any two zones and among all the different regional points of the spatial passageway through which the ion beam travels. It would be also highly desirable, but not essential for this purpose, for the values of B_x and B_y respectively to be zero (null) at the estimated or approximate center of the ion beam.

The present invention achieves and provides the user for the first time with the capability of direct adjustment and control of the magnetic field gradient dB_y/dx as an operational parameter via its unique structural arrangement. The unique arrangement of the regulator assembly also provides a substantial simplification of construction and singular assembly, which is markedly different and distinct from the conventional devices illustrated herein by Prior Art Figs. ~~A~~ 1, ~~B~~ 2 and ~~C~~ 3; and, in many instances, will require substantially less electric current in order to adjust and control the uniformity of the charged particles in the beam and achieve a useful profile. Furthermore, the usual internal variations in magnetic field strength and in magnetic field gradient are controlled and made considerably smoother with an array of coils in contact end-to-end than was previously possible by the Cartesian Multipole devices of the prior art.

III. Electromagnetic Regulator Assembly Comprising The Present Invention

The subject matter as a whole comprising the electromagnetic regulator assembly is most easily understood with particular reference to the differences between the Cartesian coordinate system used in prior art devices and the polar coordinate framework of the present invention as described herein. For the reader's convenience, the z-axis is presumed to exist at and run down the approximate center of the ion beam as it travels along its intended pathway; and the term 'downstream' signifies a location in the moving direction and pathway of the continuous ion beam as it travels from its source towards the targeted workpiece.

The regulator assembly and the manner of its use comprise the subject matter as a whole of the present invention. The assembly provides at least one linear multipole array for the generation of a contiguous magnetic field of known strength and profile; and includes a circumscribed spatial passageway which typically is of rectangular shape, has set spatial dimensions, and encompasses and bounds (using x-axis and y-axis coordinates) the entirety of a continuous ion beam (then traveling in the z-axis). The generated contiguous magnetic field of predetermined strength is generated and aligned within the confines and dimensions of the circumscribed spatial passageway. However, unlike prior art devices, the present invention is so structured and designed that the magnetic field gradient, dB_y/dx, of the contiguous magnetic field can be directly adjusted and controlled at will; and such at will adjustments and control of the magnetic field gradient is achieved by varying the electric current(s) to individual and different parts of the linear multipole array; and consequently altering the strength of the magnetic field gradient within carefully selected spatial zones and/or regions within the total volume encompassed by the circumscribed spatial passageway.

A. The Simplest Construction

Structural elements of the construction

The simplest embodiments of the present invention are exemplified and illustrated by the assembly of Figs. ~~1A~~ 6 and ~~1B~~ 7 respectively. As seen therein, the regulator assembly 10 comprises a straight ferromagnetic rod 20 of fixed length and girth sized to be somewhat longer in length than the x-axis dimension of the continuous ion beam to be controlled; and oriented to lie parallel to and at a preset gap distance from a boundary plate 60 having a plane surface 62. The straight ferromagnetic rod 20 serves as a support bar around which a plurality of individual wire coils 22

electrical energy of an appropriate current, each adjacently positioned and energized wire coil 22 independently generates an orthogonally extending and individually adjustable magnetic field of limited breadth; and the plurality of adjacently extending magnetic fields of limited breadth collectively form a contiguous magnetic field; and the strength of each magnetic field of limited breadth within the contiguous magnetic field can be individually altered at will (by varying the electrical current) to yield an adjustable and controllable magnetic field gradient over the entirety of the contiguous magnetic field. The method of adjustment is fully described below.

It will be noted and appreciated, as shown by Fig. ~~1B~~ 7, that the aligned series of multiple individual wire coils 22 constitute a multipole array 30 in which each wire coil is orthogonally wound and is orthogonally set at a different fixed position along and over the sized length of the ferromagnetic support rod; and, as shown by Fig. ~~1A~~ 6, comprises an array 30 which is congruent with (*i.e.,* coincides exactly when superimposed) and encompasses the breadth dimension 42 of the spatial passageway 40, through which the continuous ion beam travels in-situ. The orthogonal winding and positioning feature of the individual wire coils 22 illustrated by Figs. ~~1A~~ 6 and ~~1B~~ 7 is thus a unique and singular orientation; and is markedly different and distinguishable from the coiled windings of the previously known multipole lens structure illustrated herein by Prior Art Figs. ~~C~~ 3 and ~~D~~ 4 respectively. Fig. ~~11~~ 17 herein plainly shows the marked differences of the orthogonally wound and positioned coils of the present invention in comparison to the different orientation and winding of the coils in the conventional multipole structure of Prior Art Figs. ~~C~~ 3 and ~~D~~ 4 respectively.

Also, the multipole coil array 30 is preferably mounted by means of non-magnetic supports to lie parallel to the plane surface 62 of the boundary plate 60; and a preset gapped distance 44 exists between the wire coils 22 and the plane surface 62. This preset gapped

distance 44 exists between the wire coils 22 and the plane surface 62. This preset gapped distance 44 defines two of the sides of the rectangular shaped spatial volume of the passageway 40 into which the magnetic field is directed. The ferromagnetic material of the boundary plate 60 and the plane surface 62 provides a set boundary limit at which the magnetic field lines are constrained to be orthogonal with respect to the x-axis multipole coil array. Accordingly, the intervening spatial volume through which the continuous ion beam will travel (in the z-axis direction) is contained within and circumscribed by the breadth distance 42 which represents the x-axis dimension and the gap distance 44 which represents the y-axis dimension.

The underpinnings of the method for using the regulator assembly

As noted herein previously, Figs. ~~1A~~ 6 and ~~1B~~ 7 show that the plane surface 62 of the boundary plate 60 lies parallel to the y = 0 plane. The multipole coil array 30 has individual wire coils 22 wound orthogonally around the ferromagnetic rod 20 and placed separate from but adjacent to each other at predetermined locations over the linear length of the road. If different electric currents are passed through each wire coil 22, the field gradient close to the plane surface 62 will vary smoothly; but for the field gradient closer to the coils, the variation is less smooth. It would be possible to shape the abutting regions of the wire coils 22 to make smoother the change in current density and the resulting change in magnetic field gradient, but this effort is deemed to be unnecessary in practice.

Rather, it is sufficient and more practical that the charged particles in the continuous ion beam flowing from its source are made to pass in the z-axis direction through the circumscribed volume of the spatial passageway 40, which is limited by the x-dimensional distance 42 and the y-axis dimensional gap distance 44. Since the component of magnetic field B_x is constrained by

the ferromagnetic plane to be zero at the plane, it follows that B_x may be non-zero at the center of the ion beam, and therefore at some distance downstream the shape of the beam may exhibit some bending in the y-direction. This would not be sufficient to prevent its use for adjusting and controlling the uniformity of the charged particles in the beam.

A particular feature of the arrangement illustrated by Figs. ~~1A~~ 6 and ~~1B~~ 7 is that each wire coil 22 is wound on the ferromagnetic support rod 20 such that the coil extends outward from the support rod and physically restricts the size of the unobstructed spatial passageway 40. A plurality of individual magnetic field gradients of limited breadth are created by energizing each of the single coiled windings independently; and each of the independently created magnetic fields extends spatially outwards, orthogonally, in the y-axis dimension, into the gap distance 44 (*i.e.,* into the pathway of the traveling ion beam).

A major benefit and advantage of the arrayed arrangement of Figs. ~~1A~~ 6 and ~~1B~~ 7 is the formation of adjacent, but individually controllable magnetic field gradients of limited breadth which are aligned in series and which collectively form a contiguous parallel magnetic field. Each wire coil creates a zone of magnetic field gradient of limited breadth, but these collectively and cumulatively form a contiguous field which can cover and will be effective over the entire breadth distance 42 of the spatial passageway 40.

The thickness of the coils, and the reduction in the clear passage that this thickness causes, are necessary in order to create sufficient ampere turns per unit length of the rod to create the magnitude of field gradient required. Reducing the thickness of the coil would necessitate raising the current density in the coil to preserve the number of ampere turns and achieve a given field gradient. The power density in the coils rises extremely rapidly as its thickness is reduced.

The thickness of the coils is determined by this consideration, and not from any fundamental electromagnetic or ion optical consideration.

Fig. ~~2~~ 8 illustrates the effect that the excitation of an individual coiled winding 22 would have on the current density distribution along the x-axis direction in an ion beam that was non-uniform in current density, but was parallel as to charged particle trajectory. Fig. ~~2~~ 8, however, is merely illustrative of the long-recognized relationship existing between uniformity and parallelism of an ion beam.

The method of the present invention, however, begins with the converse situation and intends the reverse of the process of Fig. ~~2~~ 8. This opposite effect and attainment of greater uniformity is shown by Fig. ~~3~~ 9, where a parallel - but non-uniform - beam is adjusted and regulated to become more uniform at a target plane, and in which such greater uniformity of current density is achieved at the expense of the beam's parallelism.

As revealed by Fig. ~~3~~ 9, the actual deflections of beam are small; and the focusing or defocusing effect must always be so small that the local focal length is greater than the gap distance from the multipole array to the targeted plane. Otherwise, the individual trajectories of the charged particles within the beam will cross; and such cross-over of charged particles will give rise to irrecoverable non-uniform features in the flowing beam.

Features and limitations of the simplest construction

If one assumes that the simplest embodiment of the regulator assembly (comprising a single multipole coil array and a boundary plate and plane surface as described above) is employed and located at a travel distance of 500mm from the target plane where the silicon wafers are to be implanted, then the focal length of any part of the regulator assembly should be

significantly greater than this travel distance to avoid generating cusps and singularities in the current density.

On this basis also, the following relationships can be stated using standard electromagnetic theory [see also Figs. ~~4~~ 10, ~~5~~ 11 and ~~6~~ 12 respectively]:

The field gradient in the center of the device (assuming all the coils receive the same excitation current) within the beam is given by:

$$dB_y/dx = \mu_0 J_s/g$$

where g is the gap between the two ferromagnetic bars (or a single ferromagnetic bar and the ferromagnetic boundary plane), and J_s is the number of ampere turns in the coil per unit length in the x-direction. When only one wire coil is excited, this expression approximates the peak gradient caused by this coil, provided the coil width exceeds g. If the coils are narrower, this relationship will hold, provided several adjacent coils are excited. The magnetic field required to deflect an ion of mass M, charge q and kinetic energy U on a trajectory with a radius ρ is given by

$$B\rho = \sqrt{\frac{2MU}{q}}$$

Assume that the z-extent of the multipole device is defined by the overall z-extent of the coils – in reality, this may be slightly less and should be modeled with a finite element computer code for accuracy. This dimension is named L_m and is not tightly constrained. For practical reasons one can assign it a value of 100mm. Therefore the angle through which a given field B would deflect an ion of mass M passing though a device of effective length L_m is

B. A Preferred Construction

Structural Elements Of the Preferred Construction

A preferred embodiment of the present invention is illustrated by Figs. ~~7~~ 13 and ~~8~~ 14. As seen therein, the regulator assembly comprises two ferromagnetic bars 120 and 220, each of which is sized to be somewhat longer in linear length than the x-dimension of the traveling ion beam intended to be controlled; and is oriented to lie parallel to and at a pre-chosen gap distance144 from one another. Each ferromagnetic bar 120 and 220 serves as a straight supporting rod around which a plurality of individual wire coils 122 and 222 are orthogonally wound at a number of predetermined and different locations; and collectively create an axially aligned series of independent, separated, and adjacently located coiled windings; and form the first multipole coil array 130 and the second multipole coil array 230 respectively. The regulator assembly 110 thus comprises the first and second multipole arrays 130 and 230, which are positioned to lie parallel and in correspondence to one another while oriented along a commonly shared x-axis direction.

A component part of the overall regulator assembly are on-demand means (not shown) for introducing electrical energy of variable current (amperes) independently through each independent and adjacently positioned wire coil 122 and 222 which is orthogonally disposed along the fixed length of the support rods 120 and 220. Given the flow of electrical energy of an appropriate current, each adjacently positioned and energized wire coil 22 independently generates an orthogonally extending and individually adjustable magnetic field gradient of limited breadth; and the plurality of adjacently extending magnetic field gradients of limited breadth collectively merge to form a contiguous magnetic field; and the strength of each magnetic field of limited breadth within the contiguous magnetic field can be individually altered

Accordingly, in this preferred construction of Figs.~~7~~ 13 and ~~8~~ 14 respectively, the construct comprises two ferromagnetic bars mounted across the width of the beam on either side of it, and approximately centered on the plane y = 0. A regular array of adjacently placed wire coils is orthogonally wound around each of the two iron bars; and each orthogonally oriented wire coil disposed on the first bar is located and aligned to lie opposite and in correspondence with another discrete wire coil wound orthogonally on the second bar. The oppositely situated pairs of coils are preferably placed in precisely coinciding alignment (exact reciprocal correspondence); or the oppositely situated pair of coils may alternatively and optionally be placed in staggered alignment position (offset reciprocal correspondence). The total number of wire coils forming the array will vary and depend on the expected circumference or girth of the ion beam; but should be least four (4) wound coils in number, and often will exceed thirty (30) adjacently positioned coils disposed upon a ferromagnetic bar.

Each of wire coils 122 is typically electrically joined in common with its directly opposite counterpart wire coil 222 when they are placed in precisely coinciding alignment; however, the oppositely situated coils cannot be directly electrically joined together in those alternative embodiments where the pair of wire coils are disposed in staggered correspondence. Nevertheless, in all instances, each distanced set of oppositely situated wire coils is to be energized equally as a matched pair (*i.e.,* receive the same amount of electrical current), one on each side of the spatial passageway 140, with the electric current flowing around each coil of the matched pair in the same angular sense or direction. The pitch of the wire coils across the breadth dimension 42 of the spatial passageway 140 should therefore be less than g/2 for optimum control of dB_y/dx; but since the number of independent power sources increases as the

pitch of the wire coils is reduced, the overall cost and complexity of wiring for the assembly become decisive factors and practical considerations.

Using the constructed regulator assembly of Figs. ~~7~~ 13 and ~~8~~ 14, the amperage current which is passed into each electrically joined pair of oppositely situated wire coils (then disposed upon each of the first and second multipole coil arrays) may be independently adjusted and individually controlled. Thus, in those multipole array embodiments of the invention which typically employ between four (4) and thirty (30) wire coils per array, there will be between four and thirty matched pairs of oppositely situated wire coils electrically joined in common; and between four and thirty separate electrical connections which provide differing individual amperages to each matched pair of oppositely situated coils disposed on the array.

In addition, the individual pairs of oppositely situated wire coils placed closest to the ends of the ferromagnetic rods may be located just beyond the confines of the ion beam width; and the ends of the supporting rods in each multipole array can be increased in length beyond the last of the wire coils by an extension sufficient to ensure that the effects of the rod ends on the distribution of the magnetic field applied to the ion beam are insignificant. The size of this rod end extension will typically be at least twice the size of the set gap distance separating the first and second multipole arrays.

Moreover, if ferromagnetic material is used to connect the two ferromagnetic rods at their individual ends to form a complete magnetic yoke (as in conventionally known devices), then it is essential to place additional large wire coils on these short rod ends, which will then carry electric currents (amperages) equal to the algebraic sum of the currents in each multipole coil array, but in an electrically opposing sense or field direction. The effect on the central magnetic field profile is insignificant, provided the additional large wire coils on the support rod ends

extend well beyond the actual width of the ion beam. The stray magnetic field which may occur at some distance from the arrayed structure is somewhat greater in effect, but this flaw can be controlled with magnetic shielding (the discussion of which is outside the scope of this invention).

Thus, the consistency of the magnetic field gradient in the central region of the regulator assembly is determined by the consistency and electrical equality of the current amperage given to each pair of oppositely situated wire coils. Near the ends of each array, the magnetic gradient falls to zero and then reverses; for this reason, therefore, the disposition of the wire coils on each array must extend beyond the region in which the desired field profile must be maintained. This premise assumes that sufficient iron or steel is present in the two rod lengths of the arrays such that this material does not magnetically saturate; and this, in turn, determines the maximum x-dimensional extent and excitation level of the first and second arrays comprising the regulator assembly.

Other Characteristics

In the preferred embodiment described herein, the ferromagnetic boundary plate and plane surface of the simplest construction is dispensed with and a second multipole coil array with multiple independent and adjacently placed wire coils is situated to lie in parallel and in correspondence with the first. The first and second multipole coil arrays are separated by a total distance 2g, and the same equations stated above for the simplest construction apply.

However, the preferred embodiment of Figs. ~~7~~ 13 and ~~8~~ 14 has the advantage that if the same travel space is available for the beam, the gap distance "g" is less and the amperage current in each wire coils less. More wire coils are required; but-in the midplane of each array, the field

is a diminishing return. This problem can be partially solved, at the expense of smoothness in the magnetic field gradient, by using the following technique.

Ideally, the coils of the multipole coil arrays are not separated by gaps. However, while the practical necessity of introducing gaps between the coils is unavoidable, the intentional filling of such gaps with steel or other ferromagnetic material can allow the rods to be moved apart without increasing the gap distance between ferromagnetic components. This approach will increase the magnetic field directly, while also allowing more space for the wire coils. Thus, each wire coil disposed on the support road is purposely separated by an intervening steel spacer, which extends to the edges of the next adjacently positioned wire coil of the array. Fig. ~~9~~ 15 illustrates the intervening steel spacer arrangement for the wire coils disposed on the support rods of the first and second arrays.

The type of alternative embodiment shown by Fig. ~~9~~ 15 is also deemed to be effective for continuous ion beams of the highest magnetic rigidity. In these instances, the ferromagnetic material employed as a spacer (typically steel) must be of sufficient thickness that it does not saturate; and the pitch of the spacer must be short and small enough that the magnetic non-uniformity produced by the finite thickness of the straight support rod and spacer is not excessive. Thus, the magnetic non-uniformity is proportional to the square of the pitch of the wire coils and of the thickness of the intervening spacers.

IV. Adjustment Steps Of A Method For Improving The Uniformity Of A Continuous Ribbon Beam

The following method of improving the uniformity of a continuous ribbon beam will be seen to be a great simplification over the method described in the White AIP reference cited

closer than g to each end.

5. Embodiments of the present invention may be incorporated into any conventionally known ion implanter, such as that shown in patent 5,834,786, as shown by Fig. ~~10~~ 16 where it appears as item 200. It may advantageously be placed on the other side of the magnet 3' from the multipole position disclosed, where the beam width is slightly greater; but still is as distant as possible from the target plane WI. A divergent ion beam 1 is produced by the ion source 2 and rendered parallel within about 0.2 degrees by the magnet. The multipole arrayed assembly may be then adjusted by the Profiler and Multipole control to equalize the currents in each of the Faraday cups, with the implant target removed from the beam.

6. The ion beam uniformity can be measured by means of a traveling Faraday cup or by an array of discrete Faraday cups. For simplicity, however, an array of Faraday cups equal to half the number of coils, and aligned with the coils, can be placed in the target plane, or close behind it. The aperture of each cup is accurately the same, so that equal measurements in the cups represent a uniform ion beam. It is important that the acceptance of the measuring device in the y-direction receives the entire beam. Accuracy is compromised if the defining apertures of the measuring device are not in the target plane. Once can choose between placing the profiler hardware directly in the target plane, in which case interlocked mechanisms are required to prevent a collision between the workpiece and the profiler hardware, or placing it just behind the target plane and accepting a slight degradation in uniformity. The error is proportional to the strongest quadrupole field component generated by the multipole adjuster.

7. Embodiments of the invention may also be incorporated into an ion implanter for silicon wafers. Compared to prior art systems (including that disclosed by U.S. Patent No. 5,350,926), the beam trimmer, movable pole pieces and associated controls all have now been

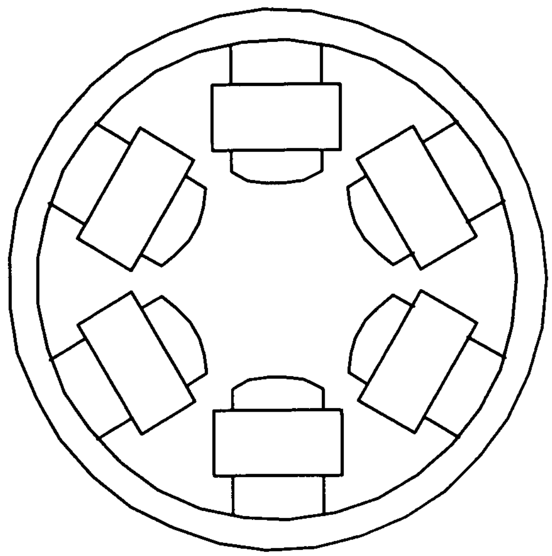


Fig. 1 (Prior Art)

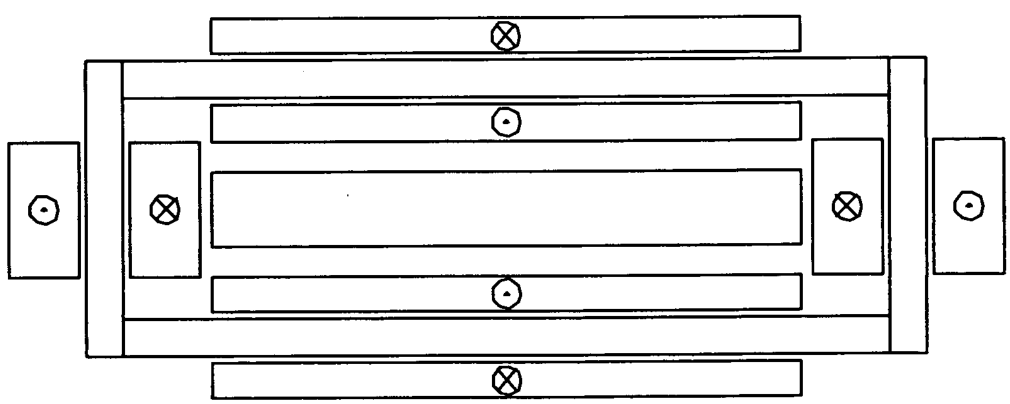


Fig. 2 (Prior Art)

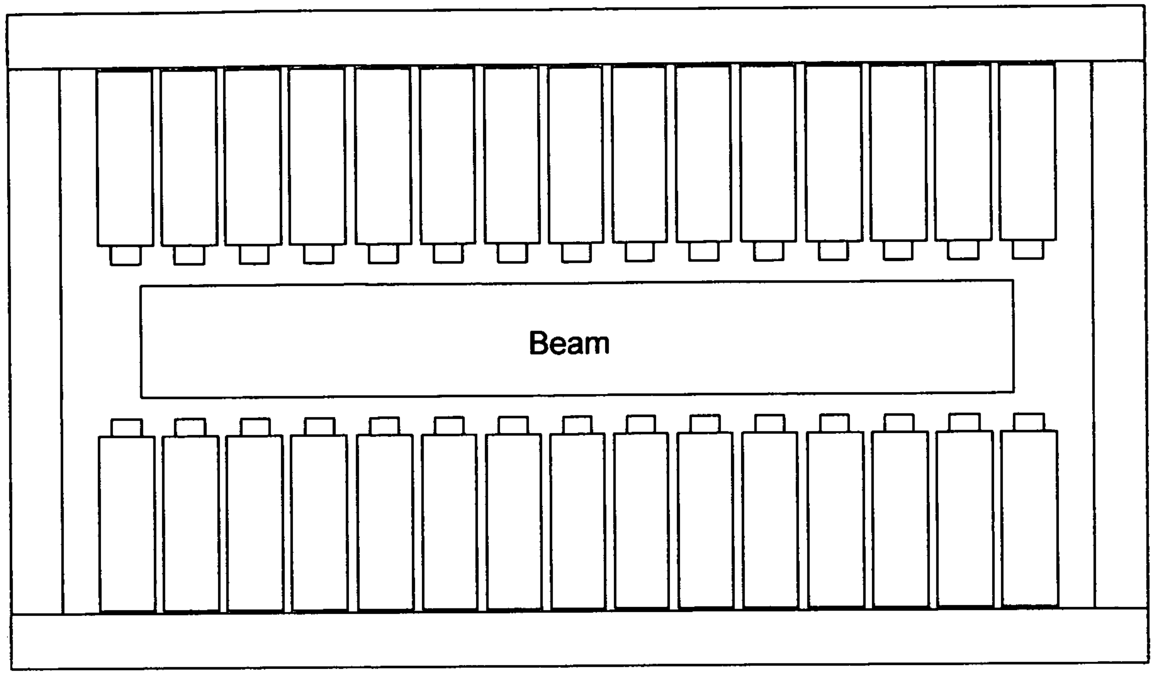


Fig. 3 (Prior Art)

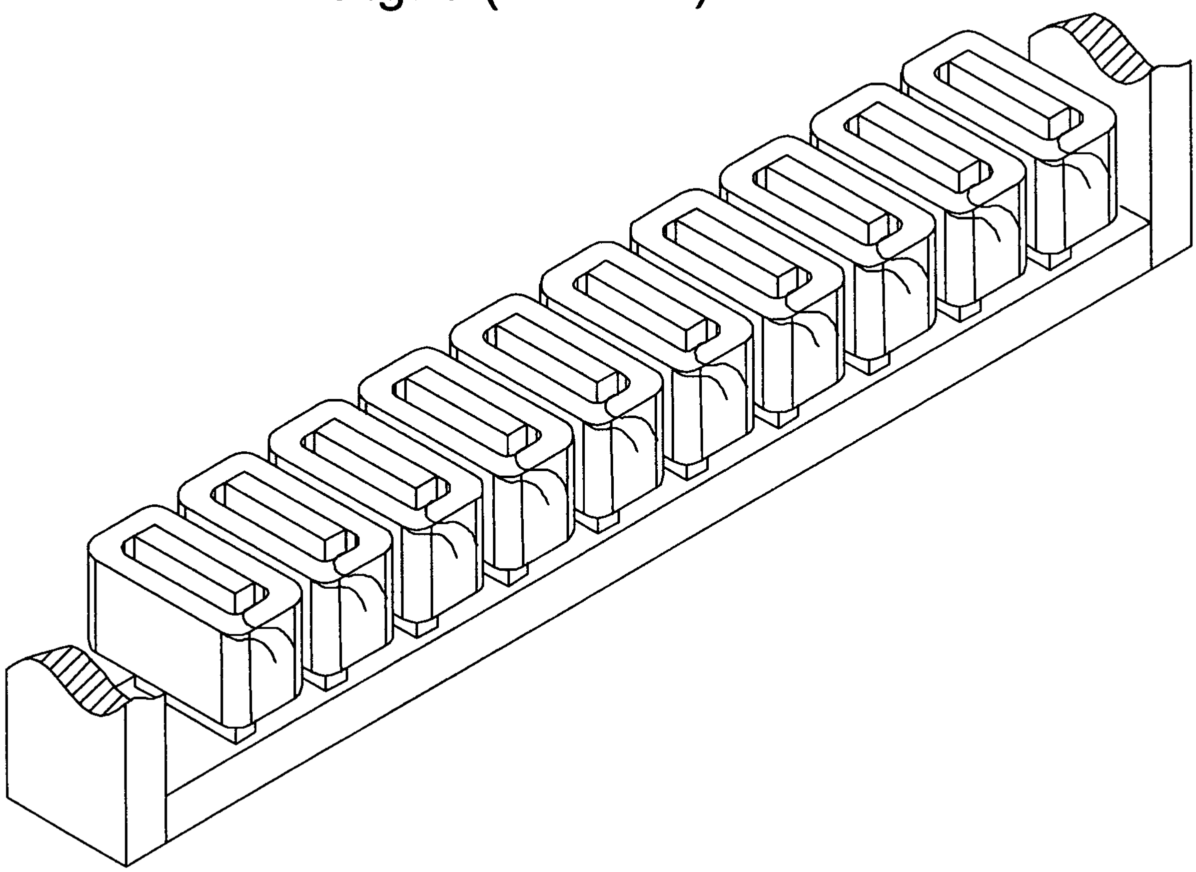


Fig 4 (Prior Art)

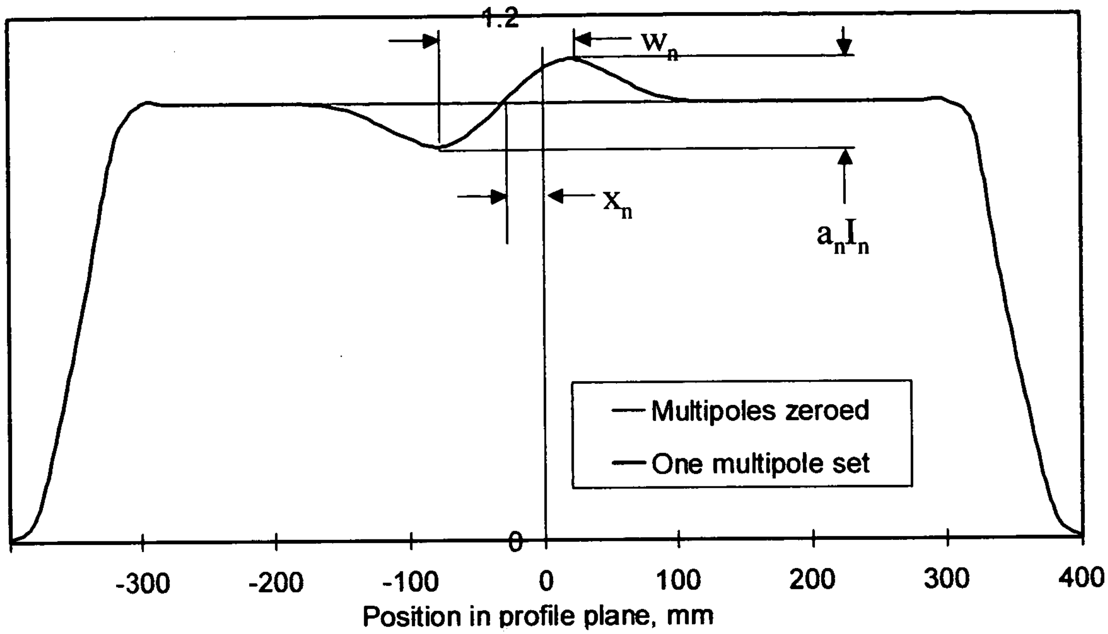


Fig 5 (Prior Art)

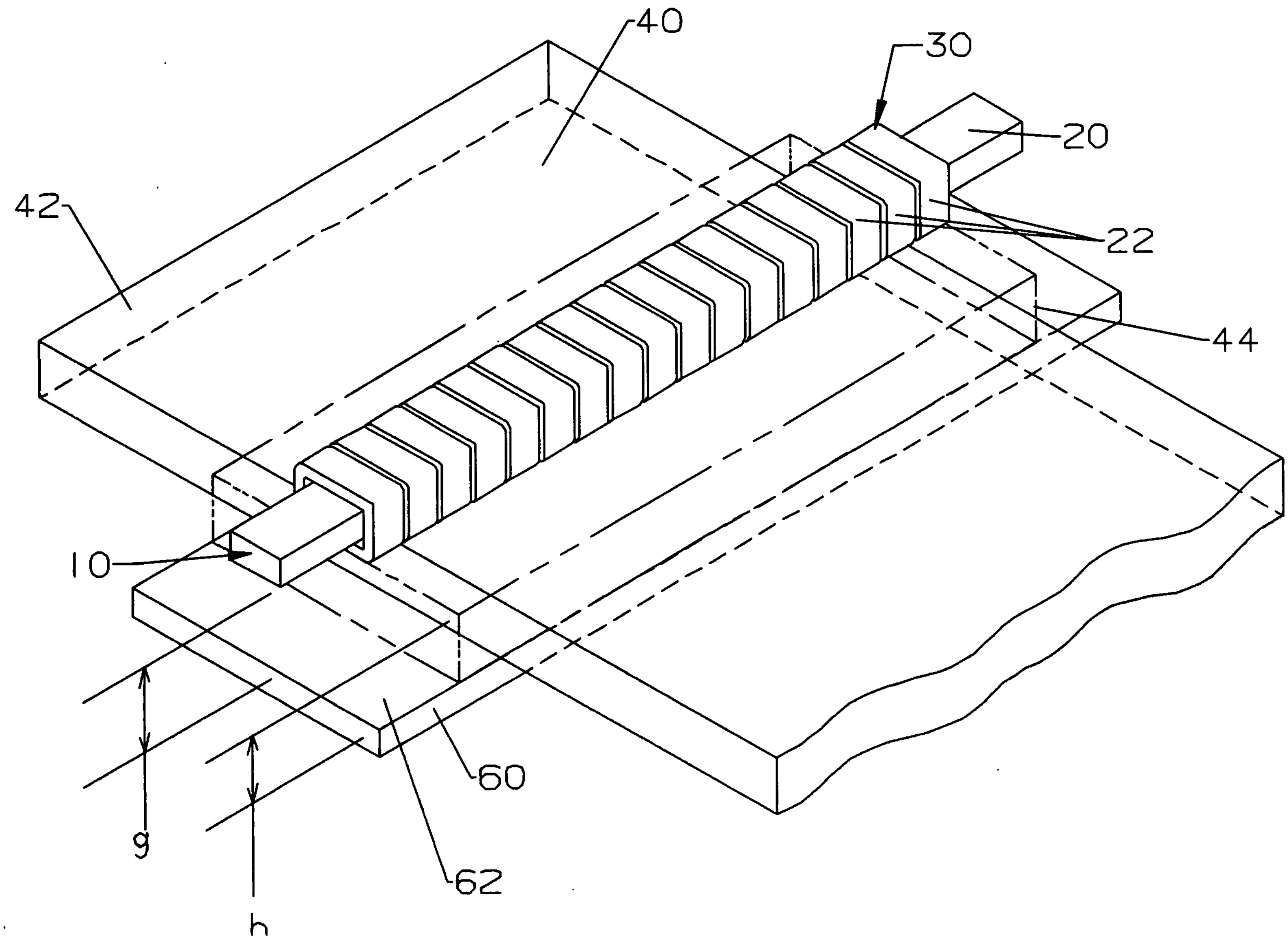


Fig 6

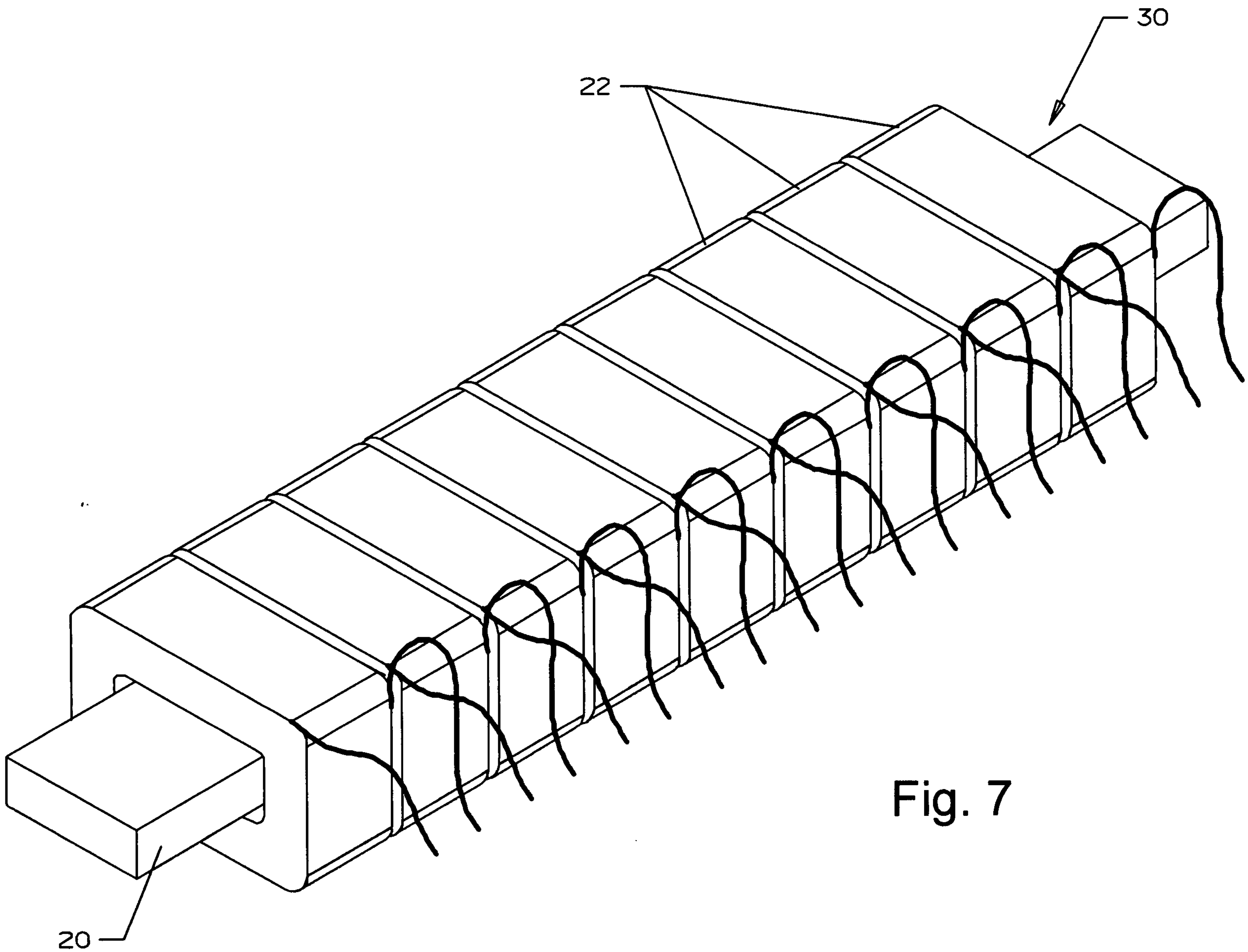


Fig. 7

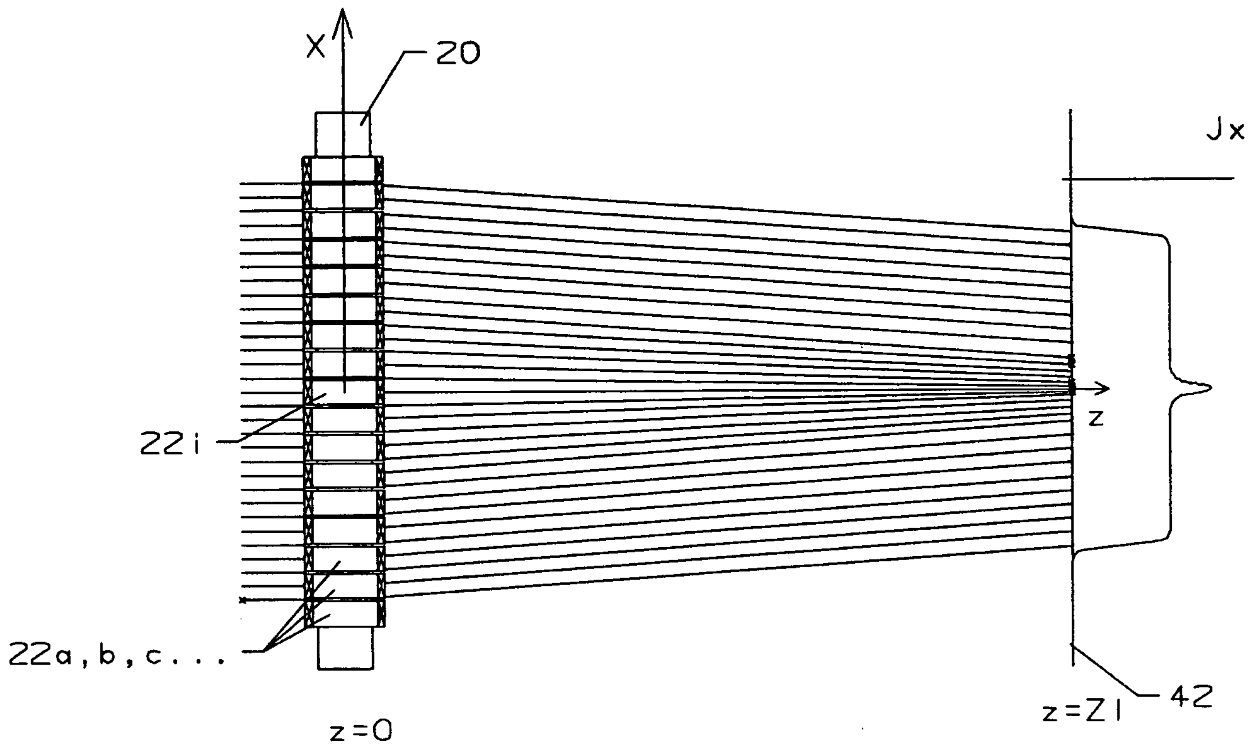


Fig. 8

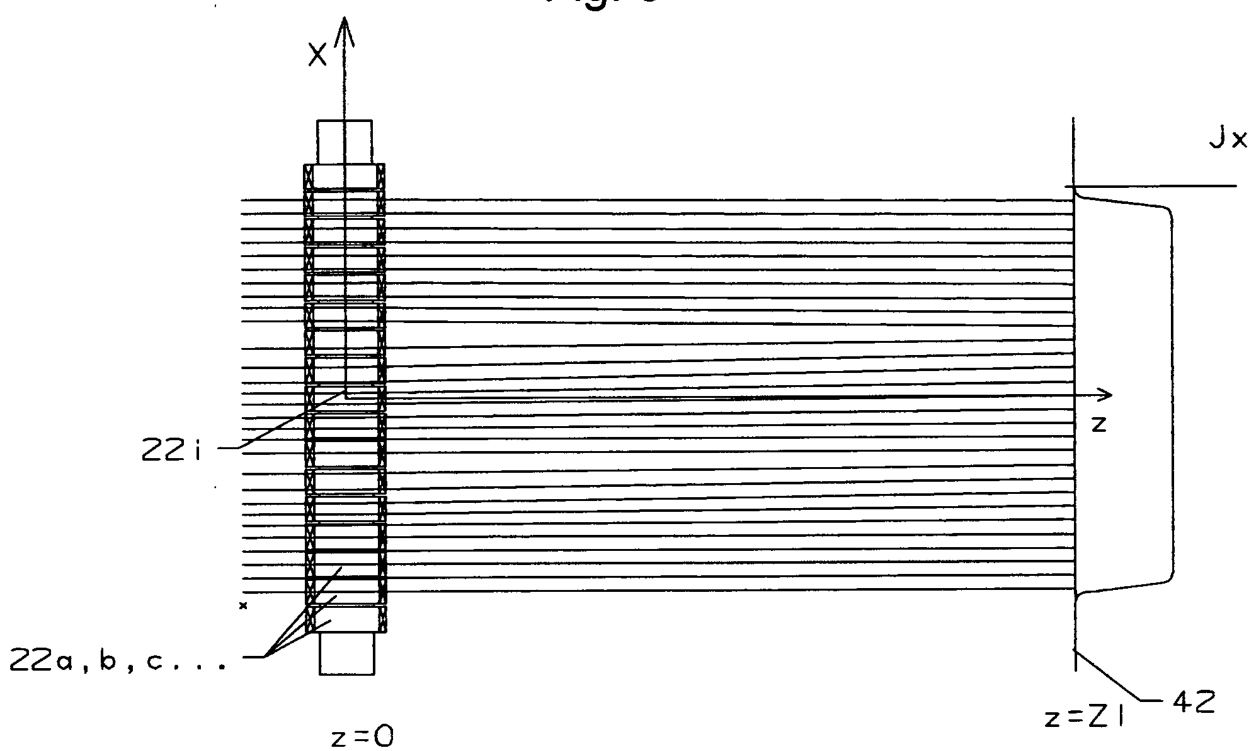


Fig. 9

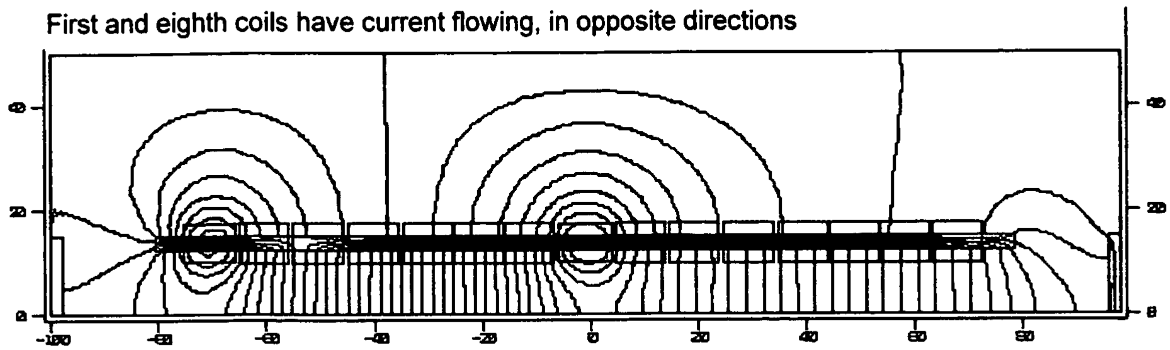


Fig 10

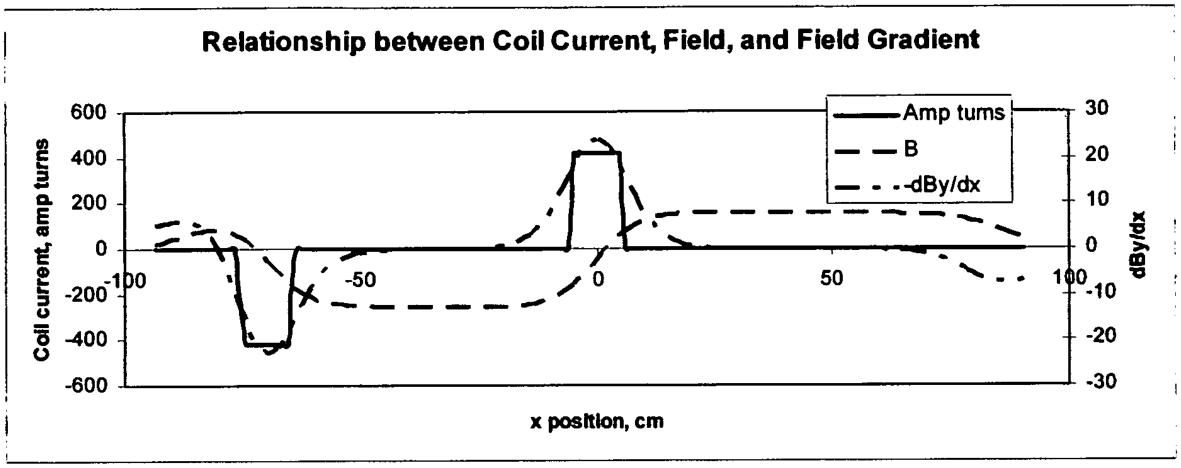


Fig 11

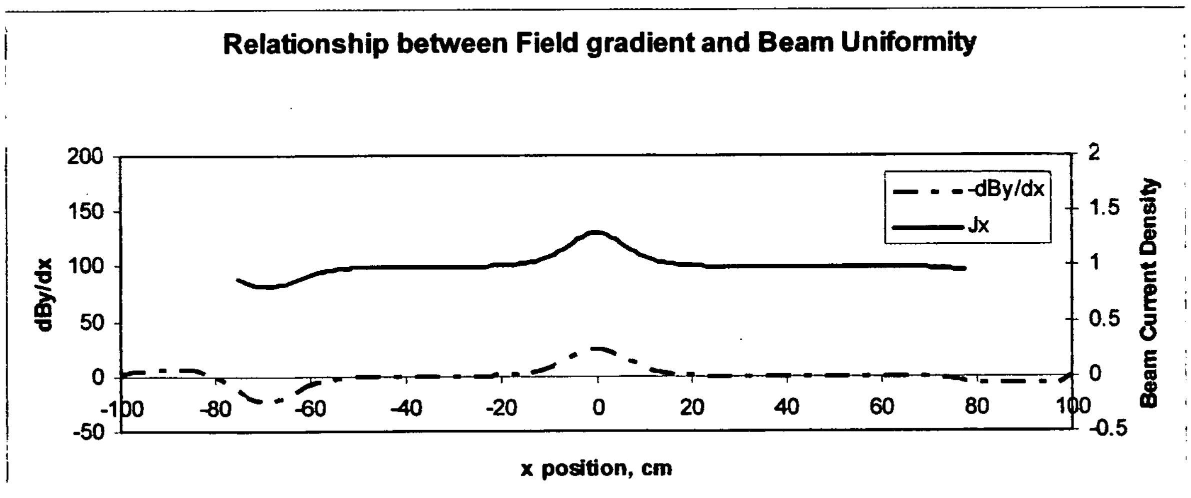


Fig 12

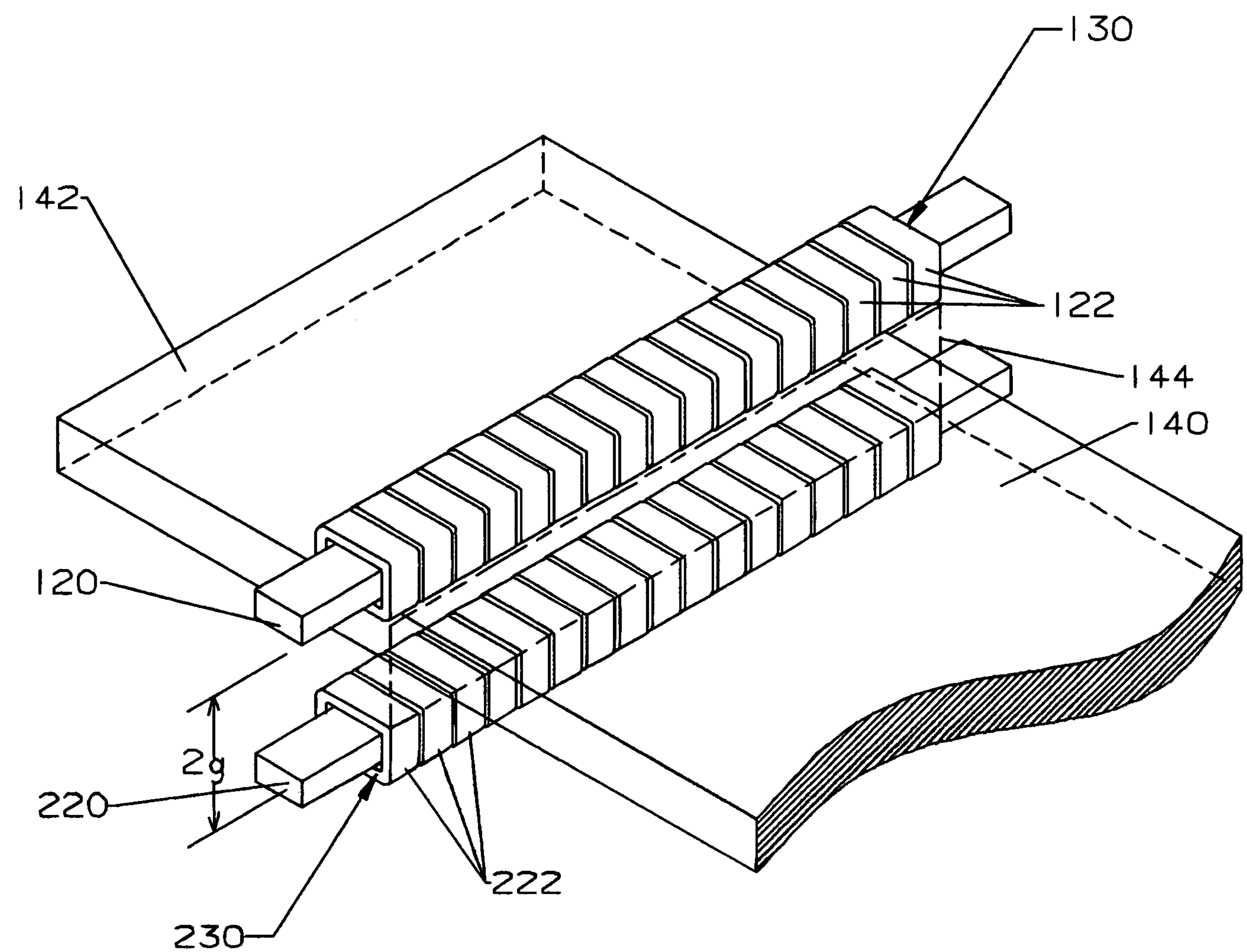


Fig. 13

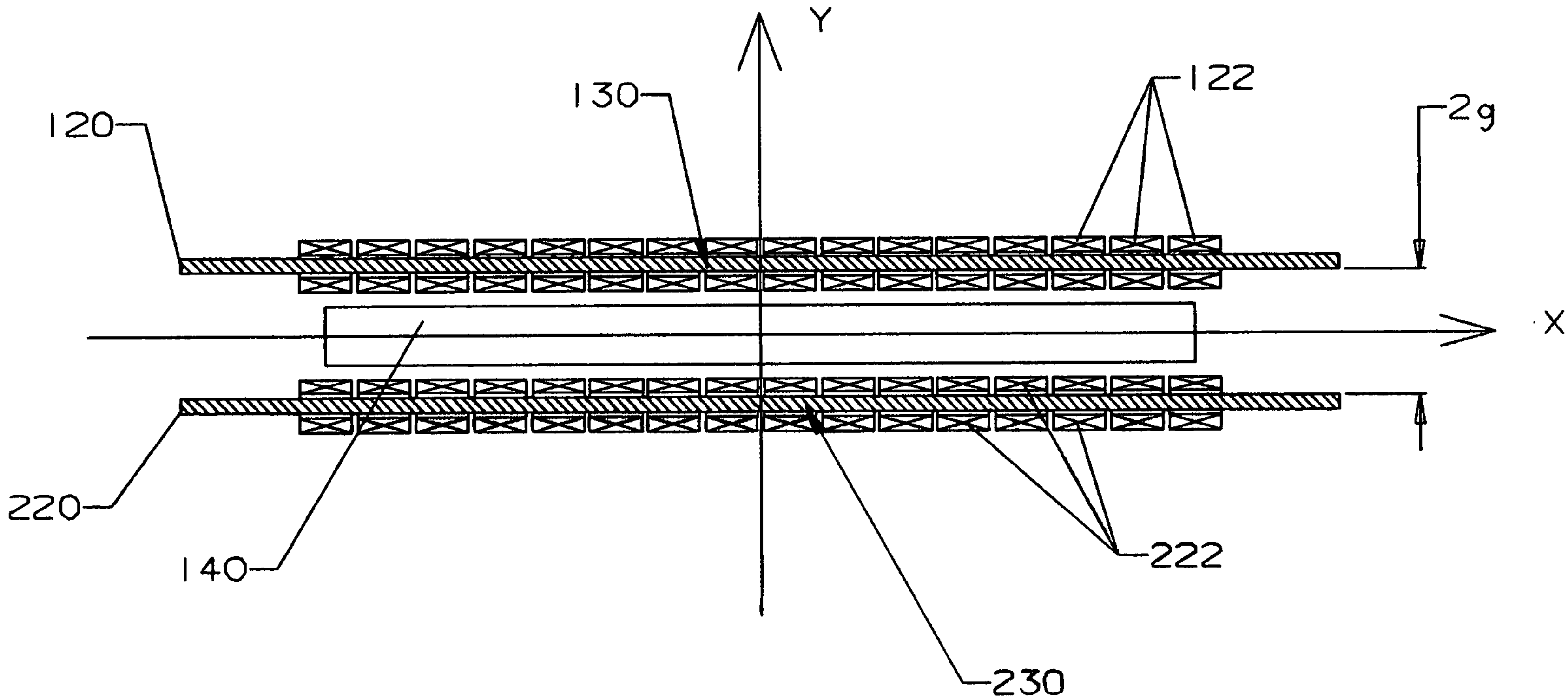


Fig. 14

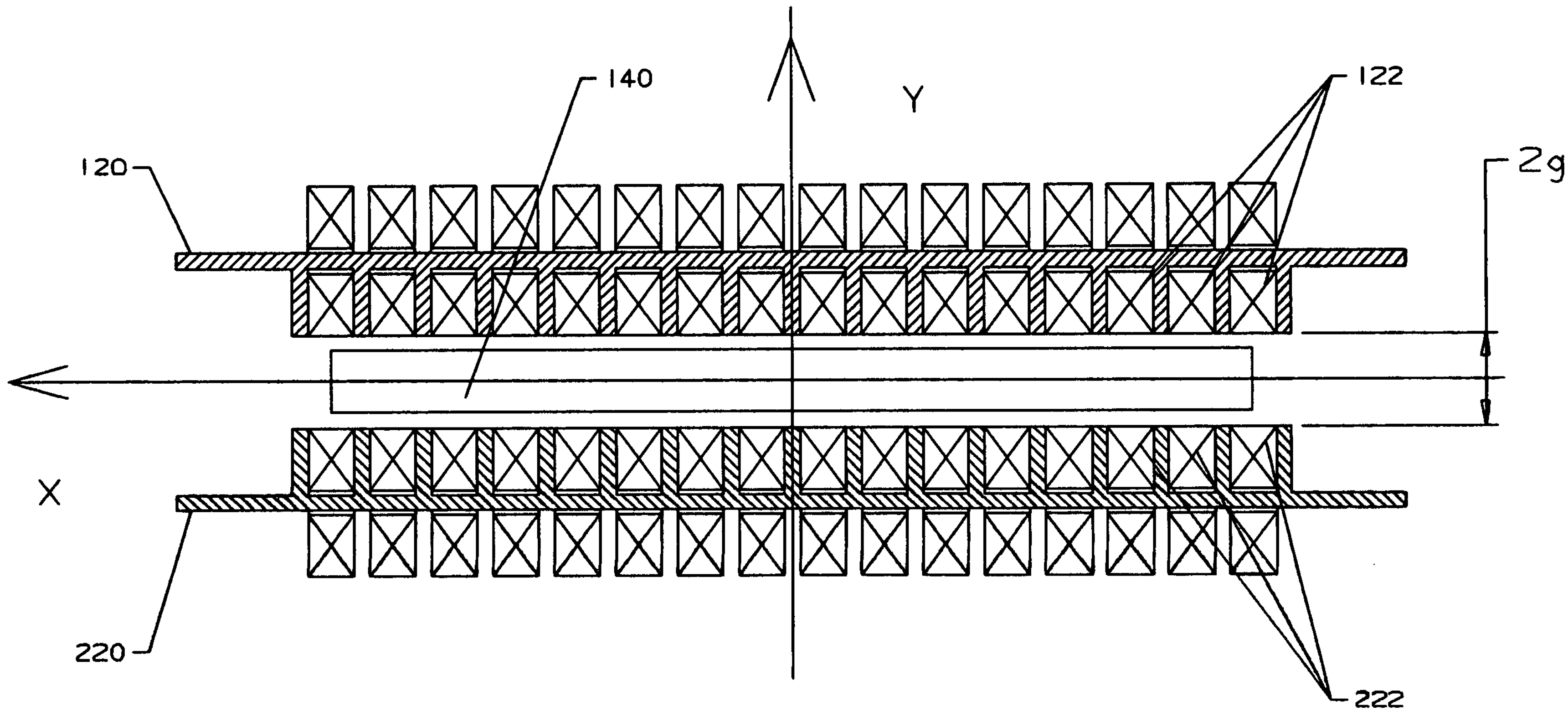
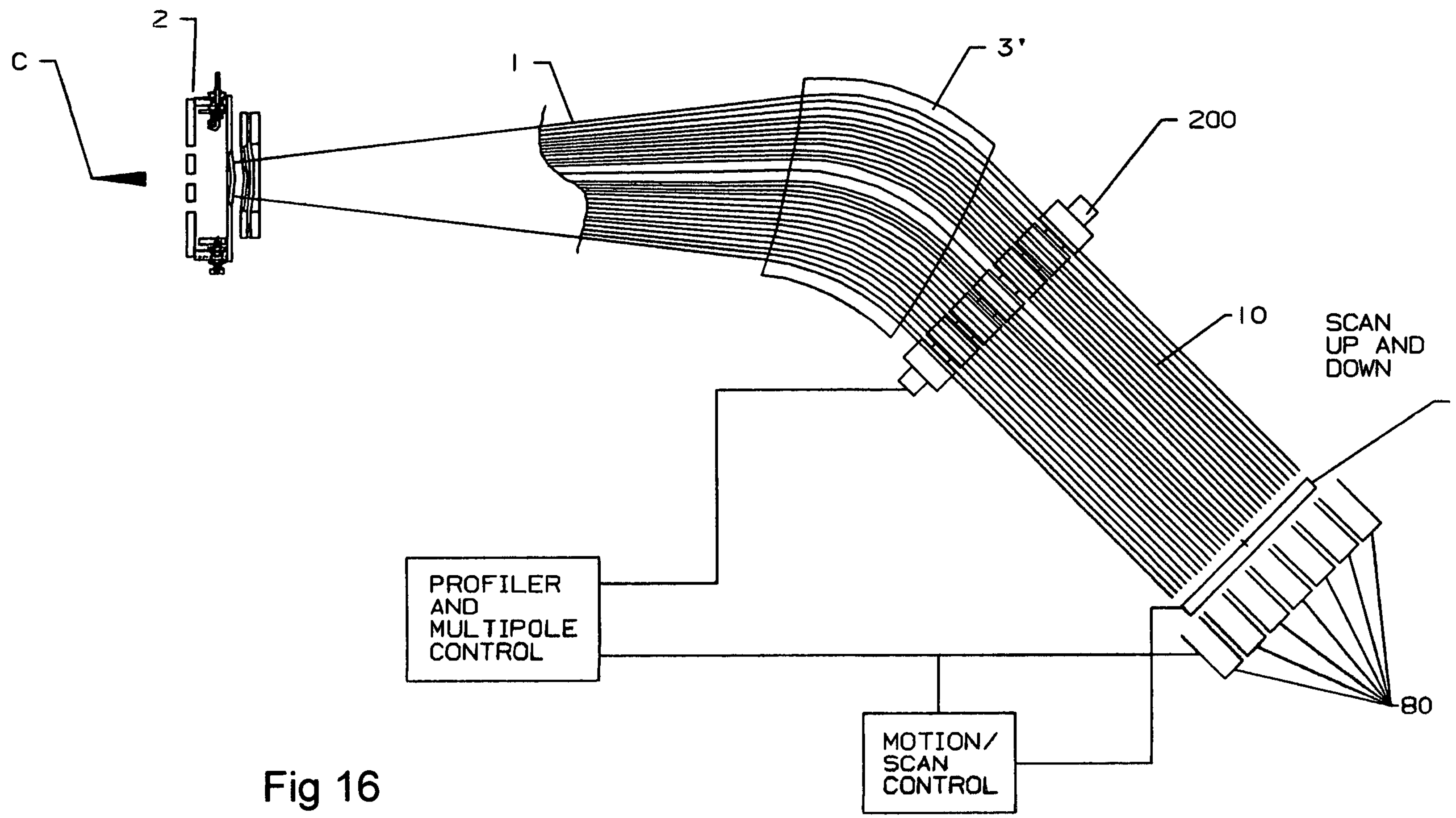


Fig. 15


C
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SCAN
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80

Fig 16

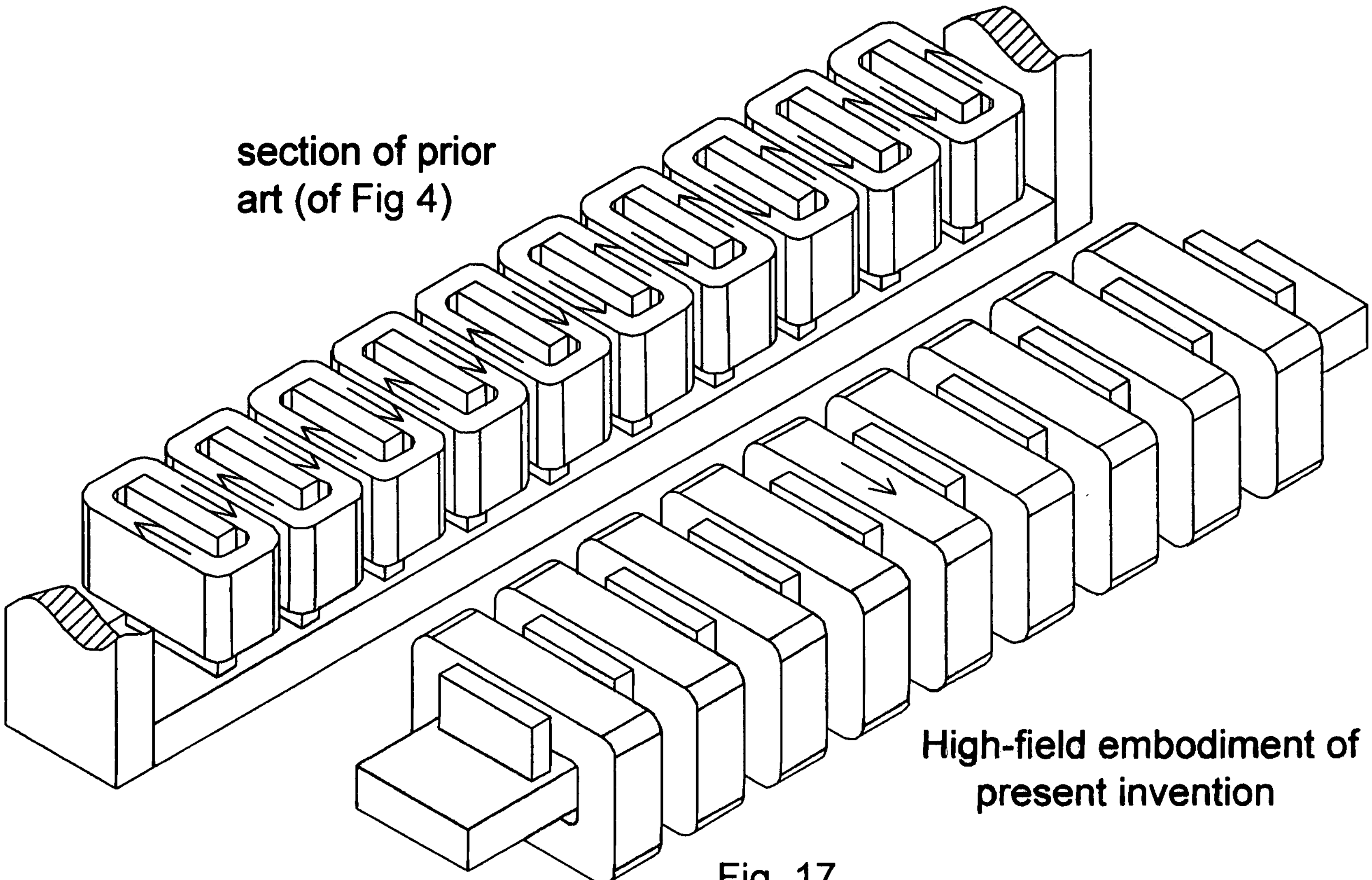
section of prior art (of Fig 4)
High-field embodiment of present invention

Fig. 17